SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS
INSTITUTE OF TRANSPORTATION STUDIES
STEPS

TRANSITIONS TOWARD LOW CARBON TRANSPORTATION FUTURES

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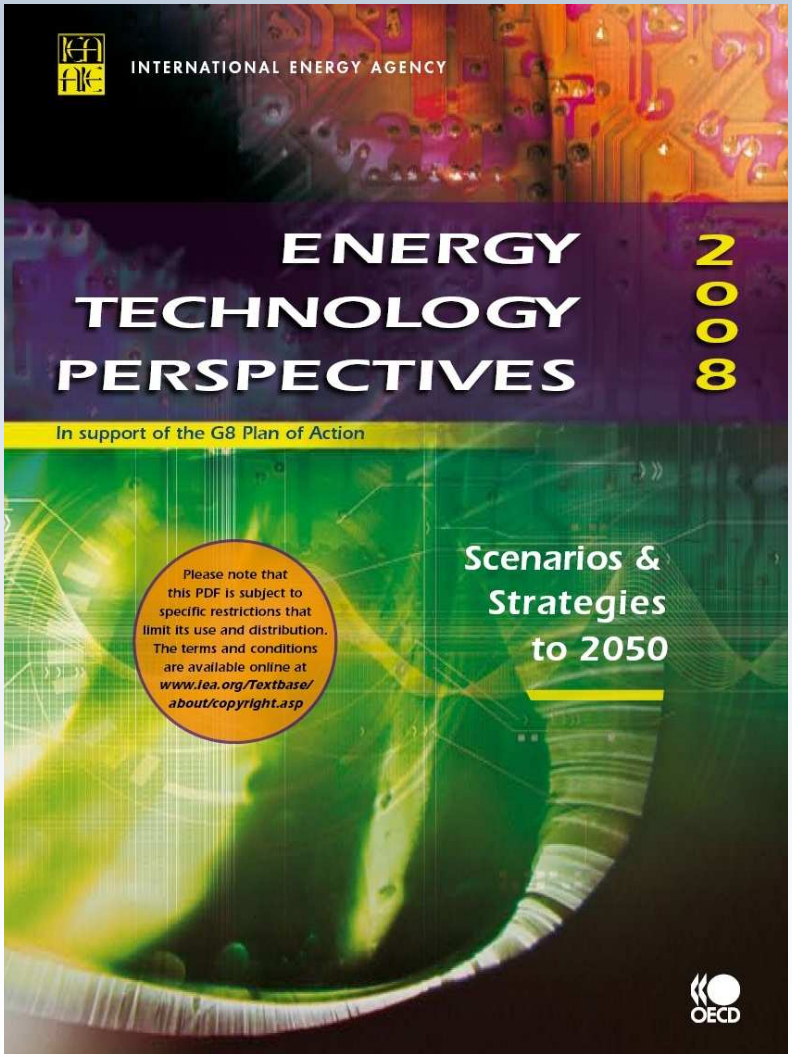
IEA SCENARIOS (ETP 2008)



Global Scope

All Energy Sectors

Transition Strategies to 2050

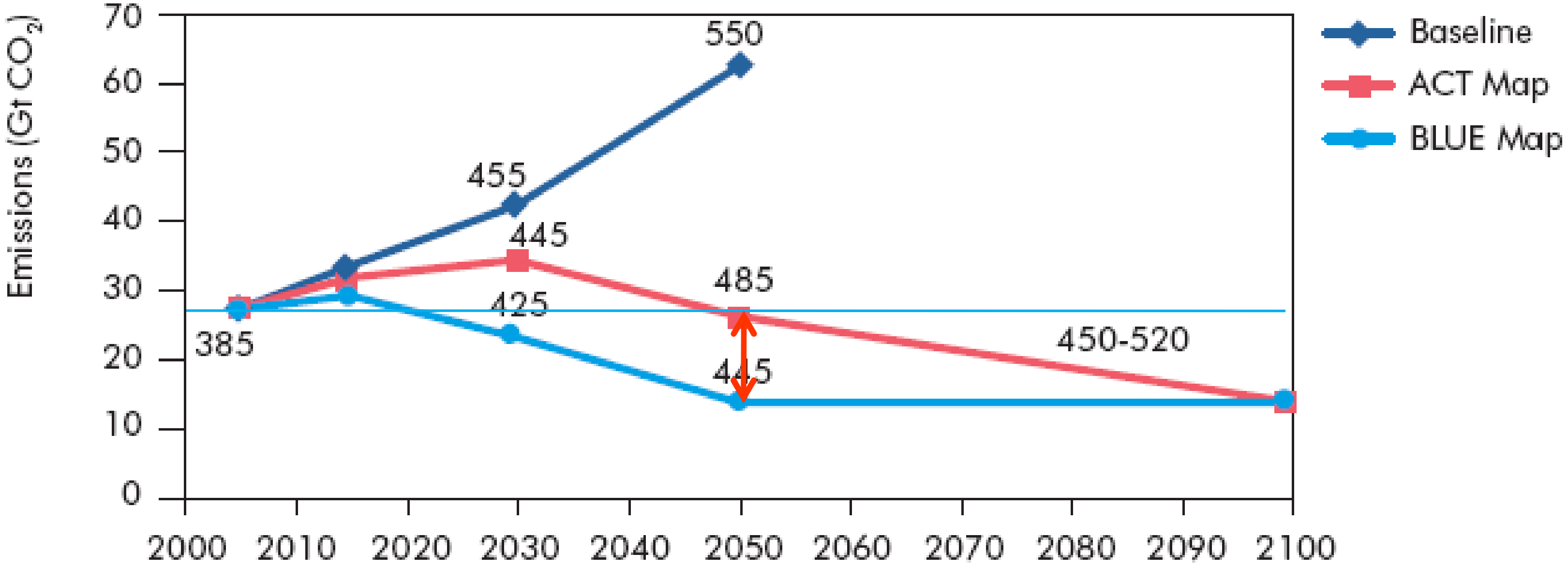
Scenarios Vary:

- Demand
- GHG Reduction Goals
- Primary resource mix
- Technology success

3 IEA SCENARIOS ANALYZED

BASELINE, ACT-Map, BLUE-Map (Stabilization at 450 ppm)

Figure 1.1 ▶ Energy-related CO_2 emission and CO_2 concentration profiles for the Baseline, ACT Map and BLUE Map scenarios



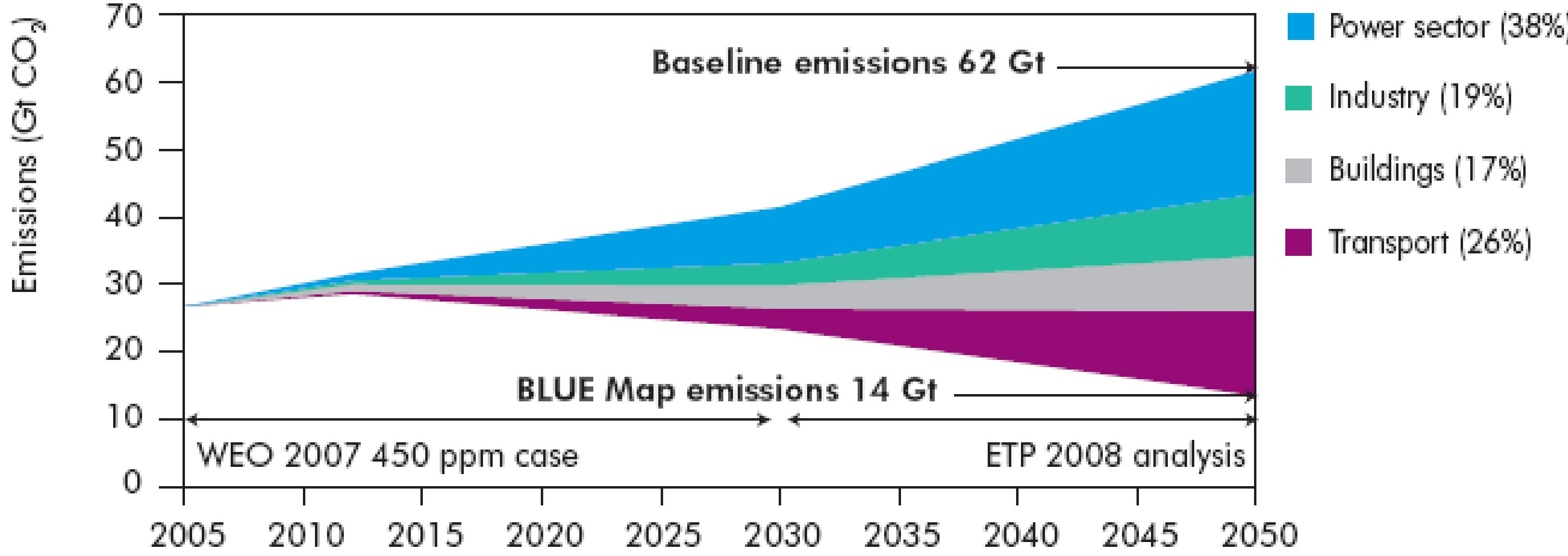
Note: Figures refer to CO_2 concentrations by volume (ppm CO_2).

Key point

Only the BLUE Map scenario is consistent with a long-term stabilisation at 450 ppm CO_2.

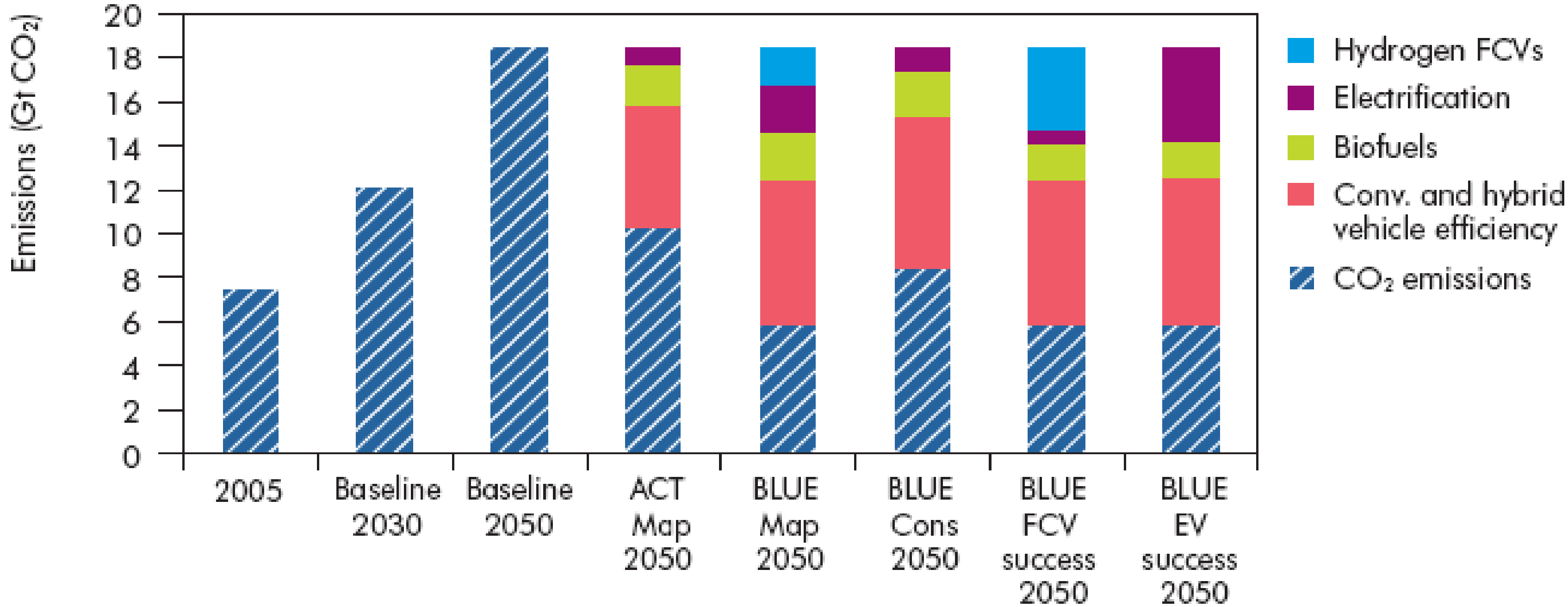
BLUE MAP STABILIZATION GOALS (CO_2~450 ppm) => GHG REDUCTIONS NEEDED IN ALL ENERGY SECTORS BY 2050, INCL. TRANSPORT

Figure 2.3 ▶ Reduction of energy-related CO_2 emissions from the Baseline scenario in the BLUE Map scenario by sector, 2005-2050



BLUE MAP TRANSPORT SECTOR GHG EMISSIONS

HIGHER VEHICLE EFF. => 50% of CO_2 EMISSIONS CUT; BIOFUELS, ELEC & H_2 FCVs => OTHER 50%

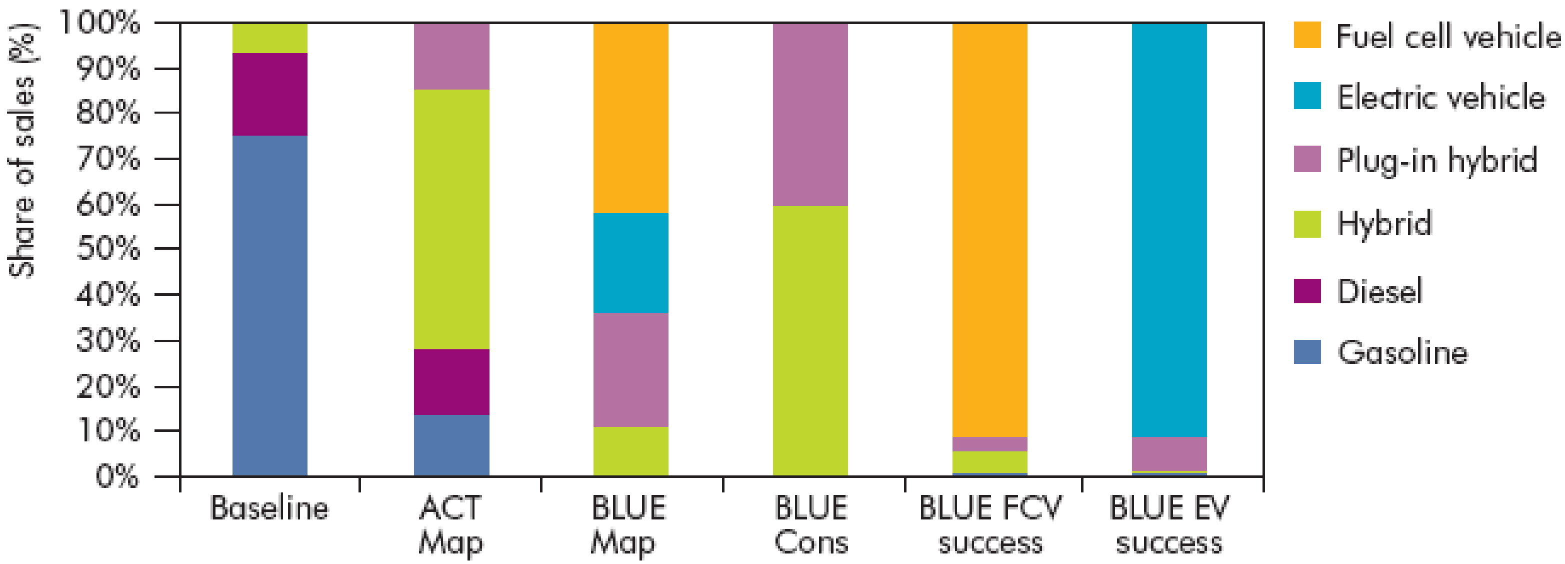


Key point

Improved fuel efficiency accounts for half of the CO_2 emissions reduction in the BLUE Map scenario: the combination of biofuels, electric and fuel cell vehicles accounts for the other half.

LOWER CARBON FUTURES =>
INCR. SHARE OF HEV, PHEV, BEV AND H_2FCV LIGHT DUTY VEHICLES

Figure 15.7 ▶ Light-duty vehicle sales shares by scenario, in 2050



Key point

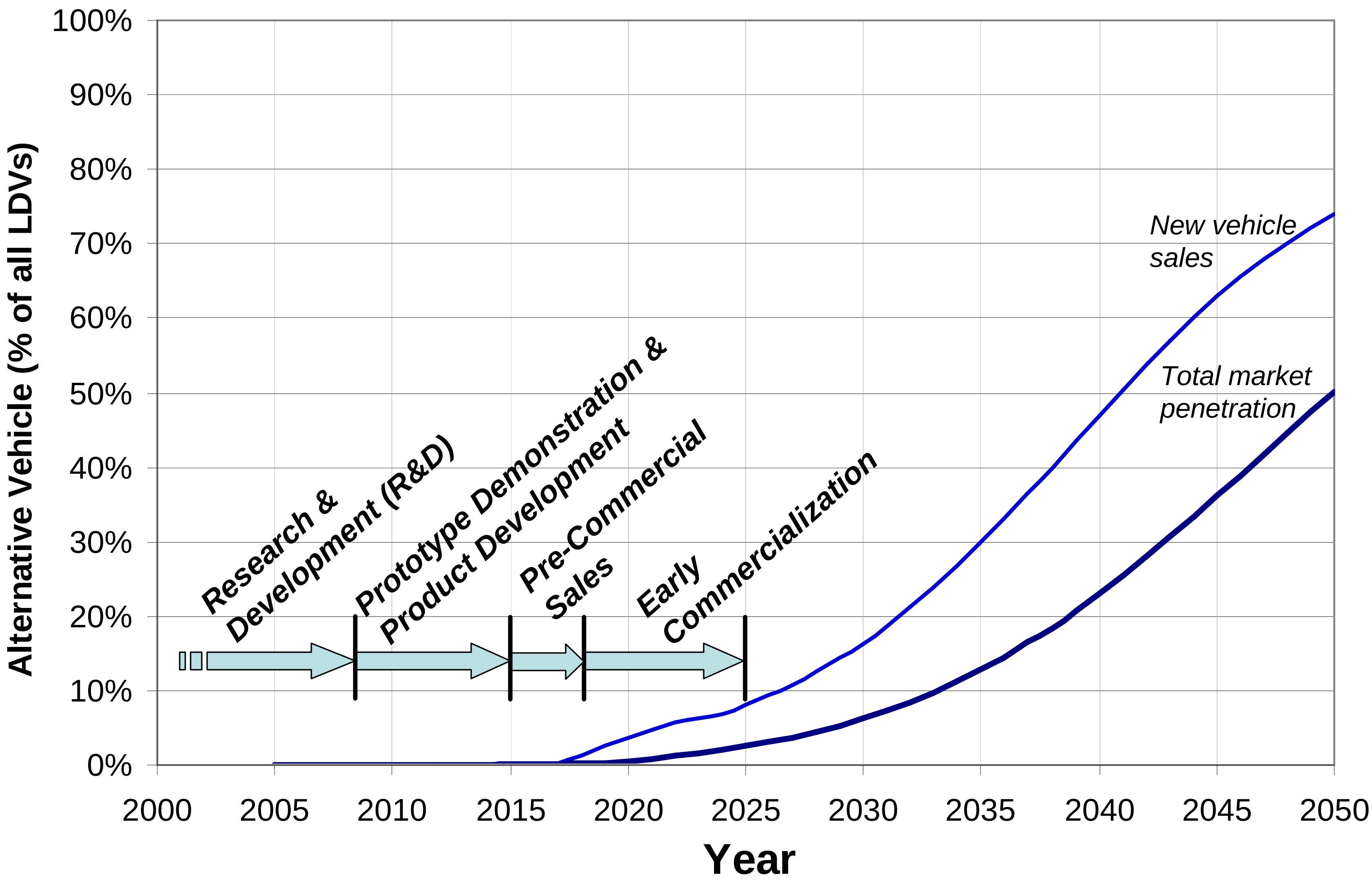
Moving from the Baseline to the ACT Map and the BLUE scenarios, an increasing share of hybrids, plug-in hybrids, and finally electric and fuel cell vehicles is seen.

GHG SCENARIO MESSAGES

- Meeting long term (2050) goals of 50-80% GHG emissions reduction is extremely challenging.
- Deep cuts in GHG emissions => major changes in transportation
- Need portfolio approach (efficiency, de-carbonized primary source for fuels, VMT reduction)
- Very low-C will likely involve significant use of electric vehicles by 2050 (Battery EVs and/or FCVs) in Light Duty Sector
- Given long lead time for change, need to start now to achieve major market share/fleet penetration by 2050.

ZEV Technologies, Policies KEY for GHG Goals

TRANSITIONS TAKE TIME:
VEHICLE COMMERCIALIZATION STAGES



Source: Cunningham, Gronich and Nicholas, presented at the NHA Meeting, March 2008.

ANALYZE LOW CARBON FUEL/VEHICLE SCENARIOS (US LDV focus)

Estimate

- **greenhouse gas (GHG) emissions**
- **gasoline consumption**

Relative to a **REFERENCE** case where no advanced technologies are implemented

Examine **transition costs** to bring FCV or PHEV technology to cost competitiveness.

SCENARIOS

1) **H2 SUCCESS** H2 & fuel cells play a major role beyond 2025

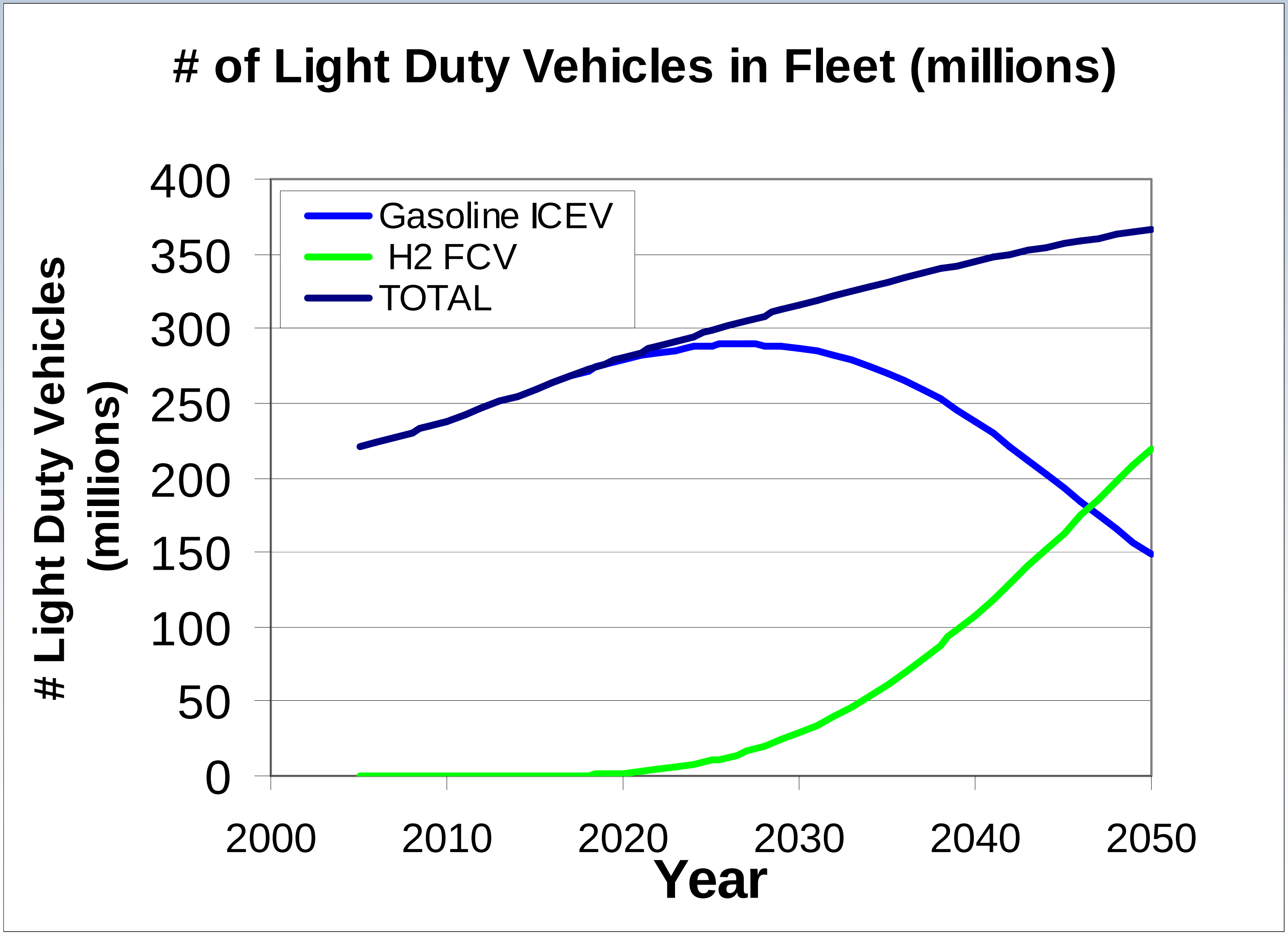
2) **EFFICIENCY** Currently feasible improvements in gasoline internal combustion engine technology are introduced

3) **BIOFUELS** Large scale use of biofuels, including ethanol and biodiesel.

4) **PLUG-IN HYBRID SUCCESS** PHEVs play a major role beyond 2025

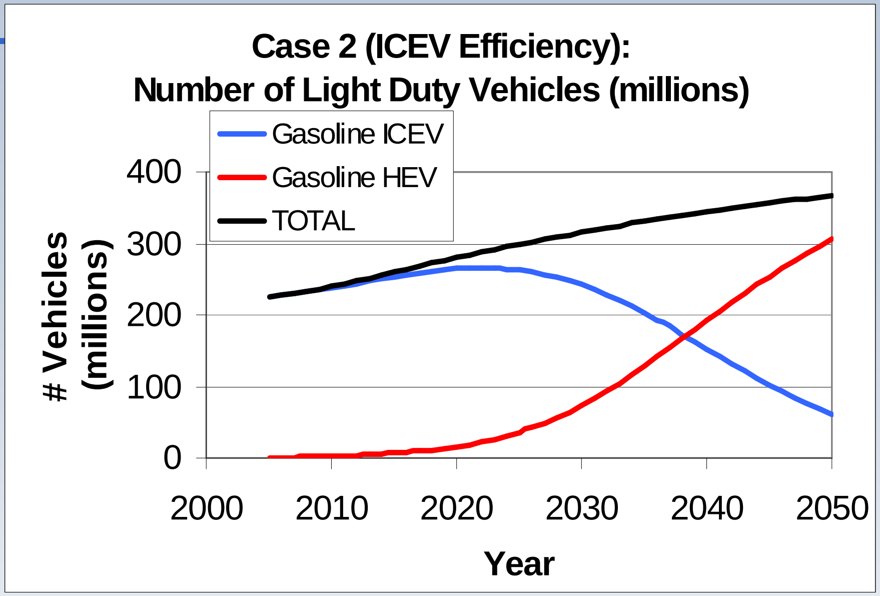
5) **PORTFOLIO APPROACH** More efficient ICEVs, biofuels, and FCVs or PHEVs introduced

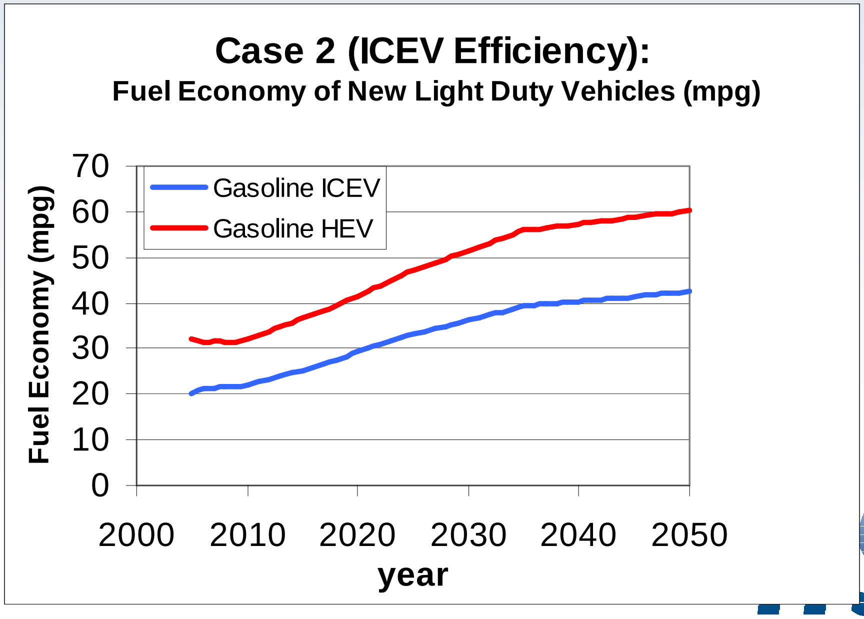
CASE 1: H2 SUCCESS (NRC 2008)



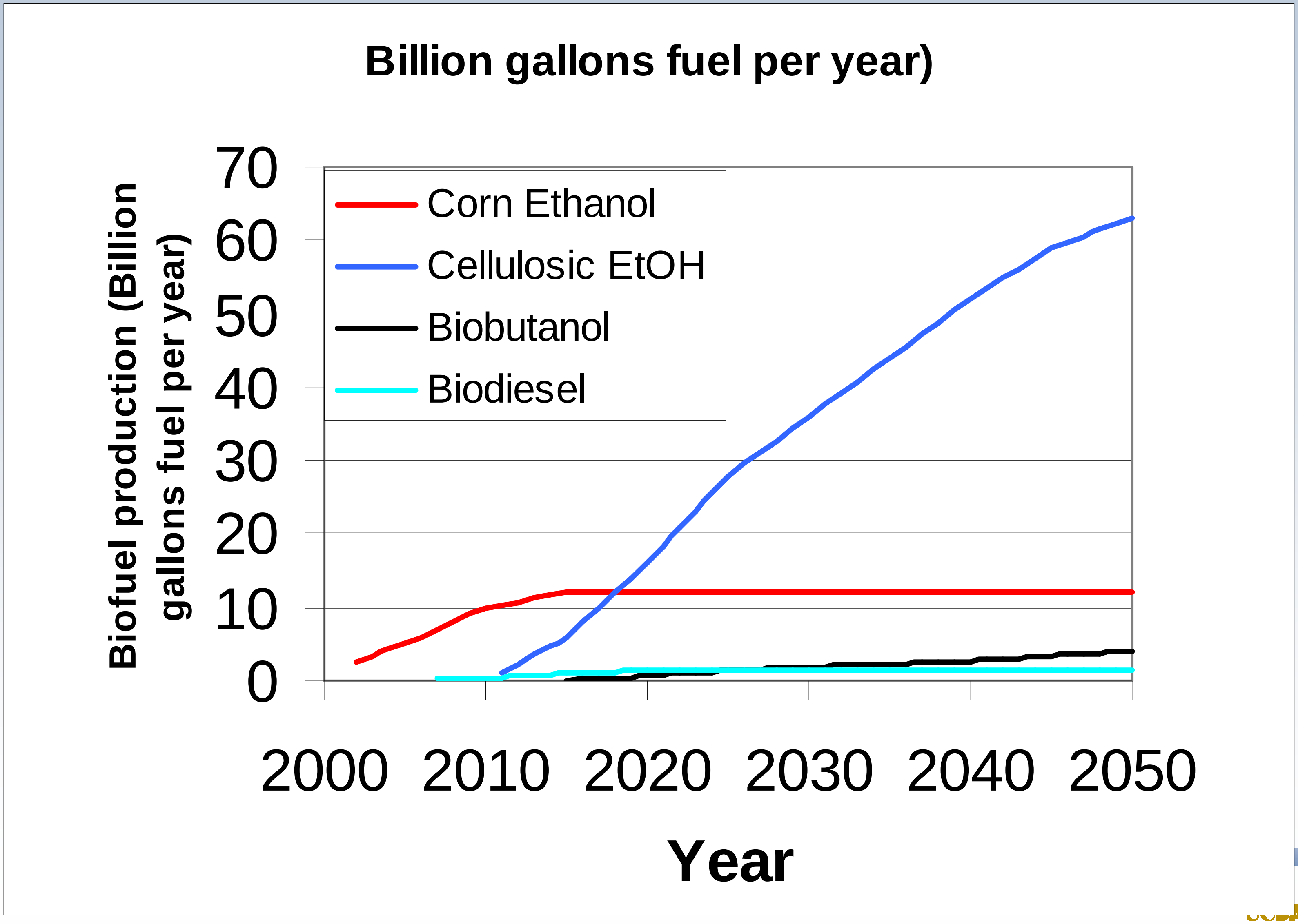
CASE 2: ICEV EFFICIENCY

- Currently available improvements in gasoline internal combustion engine technology used to increase efficiency
- The fuel economy of gasoline vehicles assumed to improve
  - 2.7 %/year from 2010-2025
  - 1.5 %/year from 2026-2035
  - 0.5%/year from 2036-2050
- Gasoline HEVs dominate; no FCVs or PHEVs





CASE 3: BIOFUEL SUCCESS

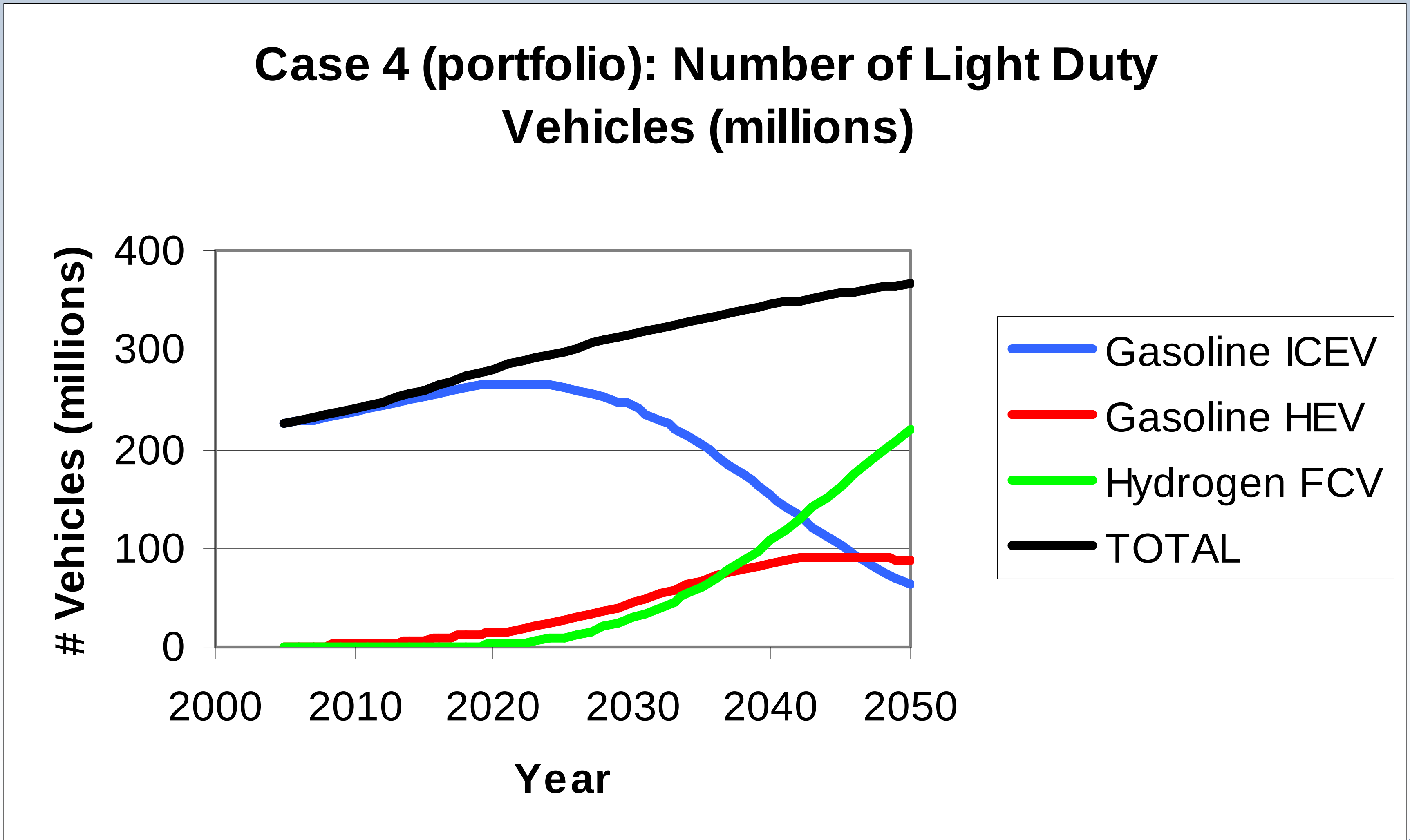


CASE 4: PHEV SUCCESS

- Introduce PHEVs at the same rate as H2 FCVs, but start earlier (2010).
  - 1 million PHEVs on road by 2017
  - 10 million by 2023
  - 220 million PHEVs (60% of fleet) in 2050
- 2 vehicle types: PHEV-10s, PHEV-40s
- 2 electricity grid mixes (EIA; EPRI/NRDC)
- PHEV Gasoline and electricity use based on lit survey of models by MIT, NREL, ANL

CASE 5: PORTFOLIO APPROACH

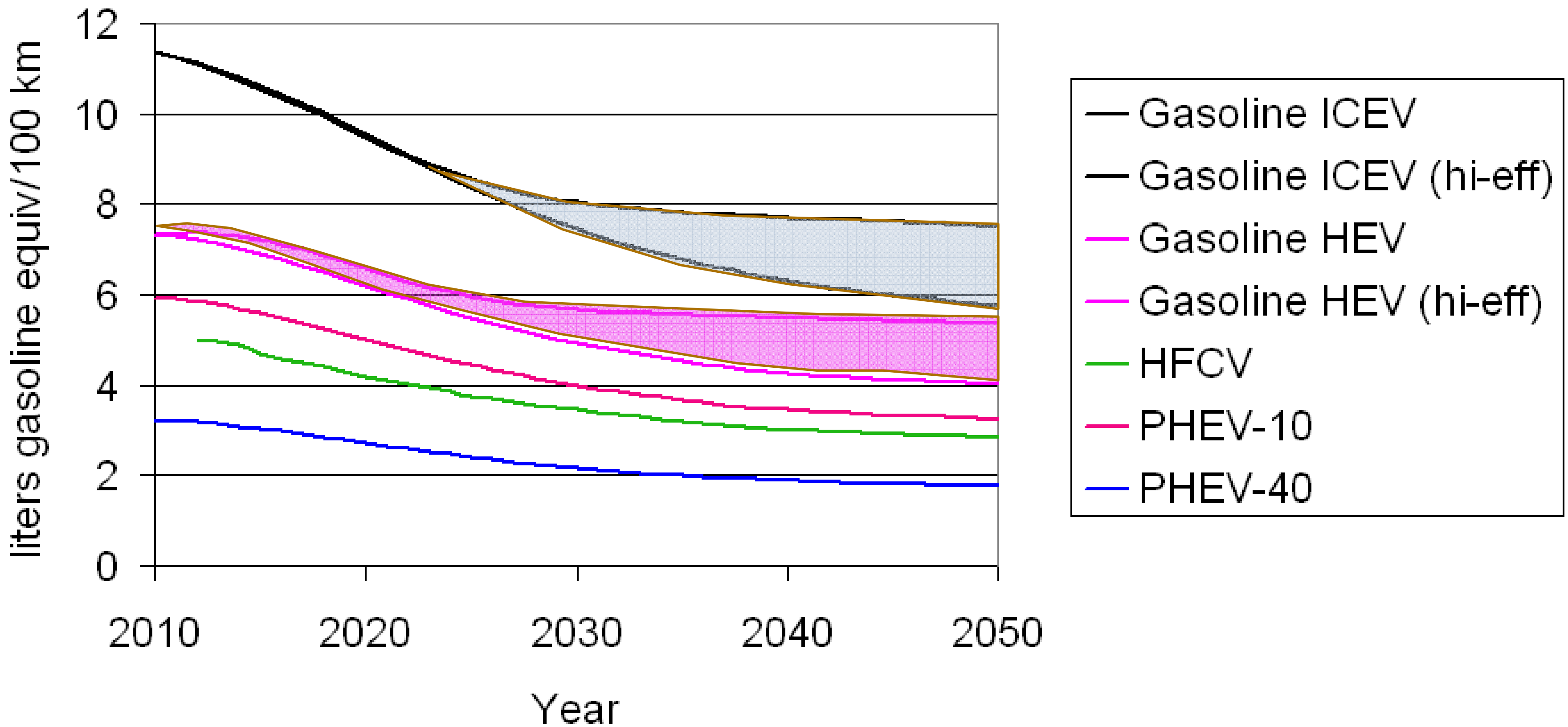
Efficient ICEVs + Biofuels + Adv. Veh.



Fuel Use for Alternative Vehicles

(fleet average) liters gasoline eq/100 km

electricity use in PHEVs not included



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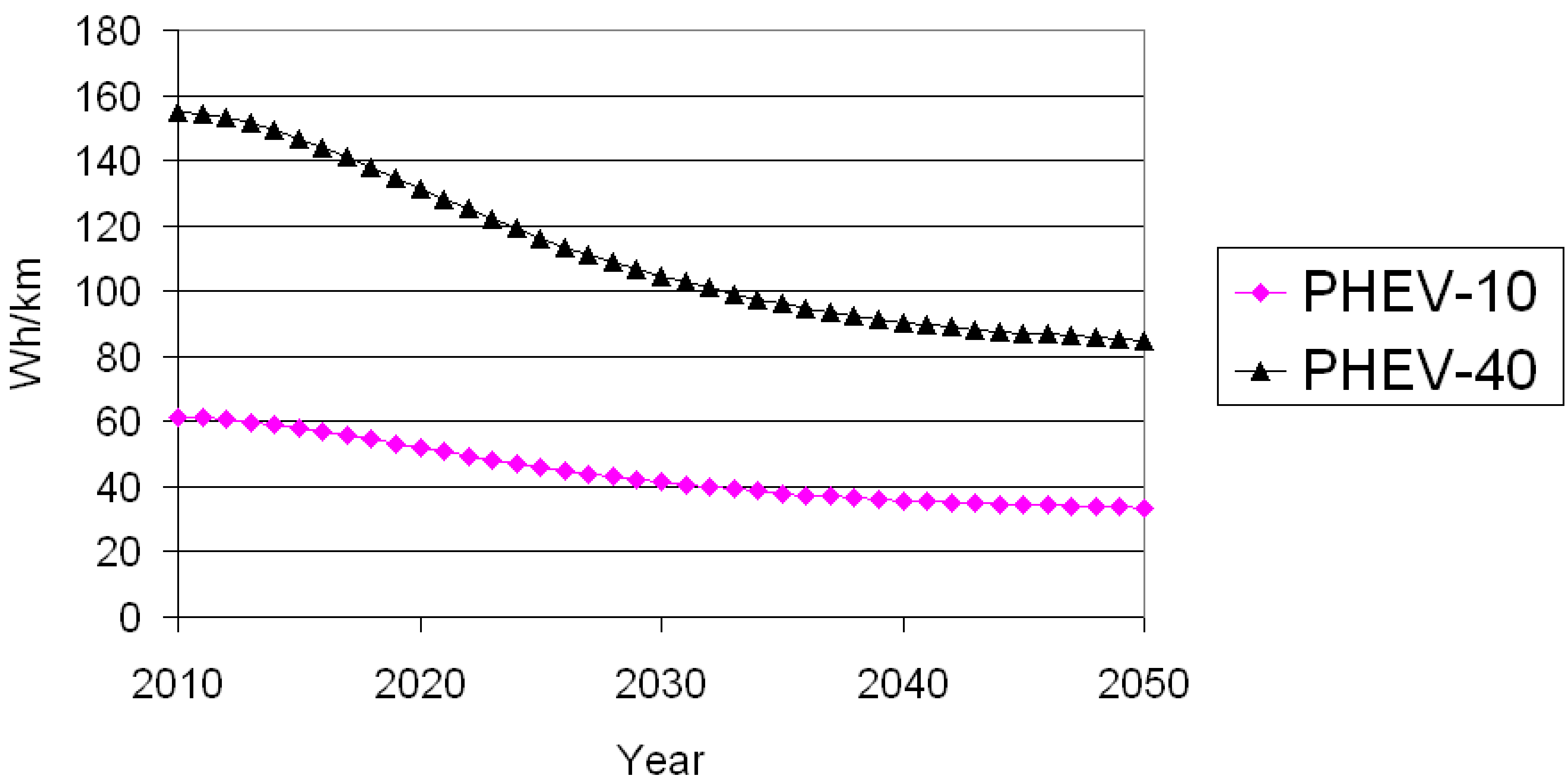
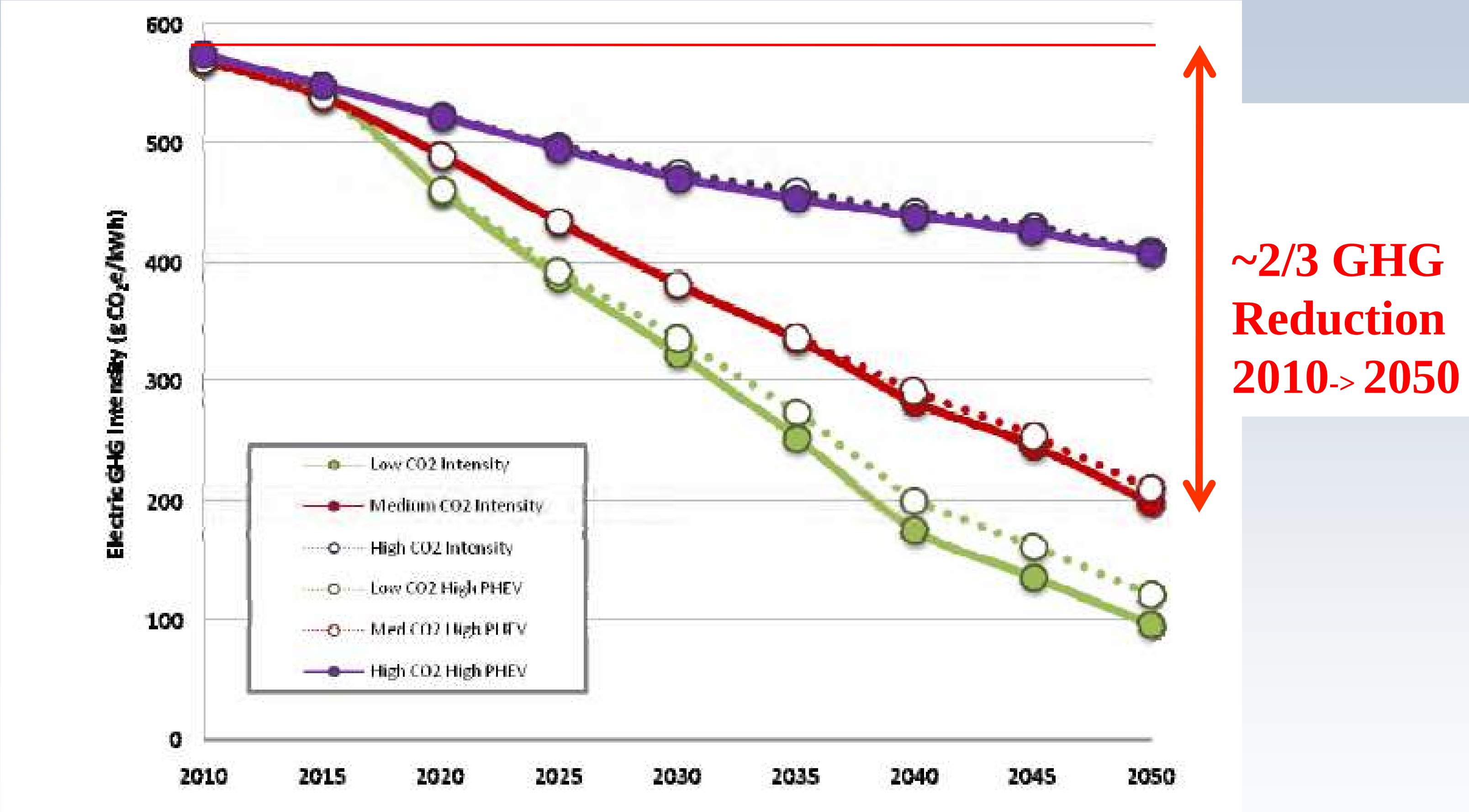
Assumed Electricity Use in PHEVs Wh/km (over drive cycle)



GHG emissions Intensity for Future Low-C Grid

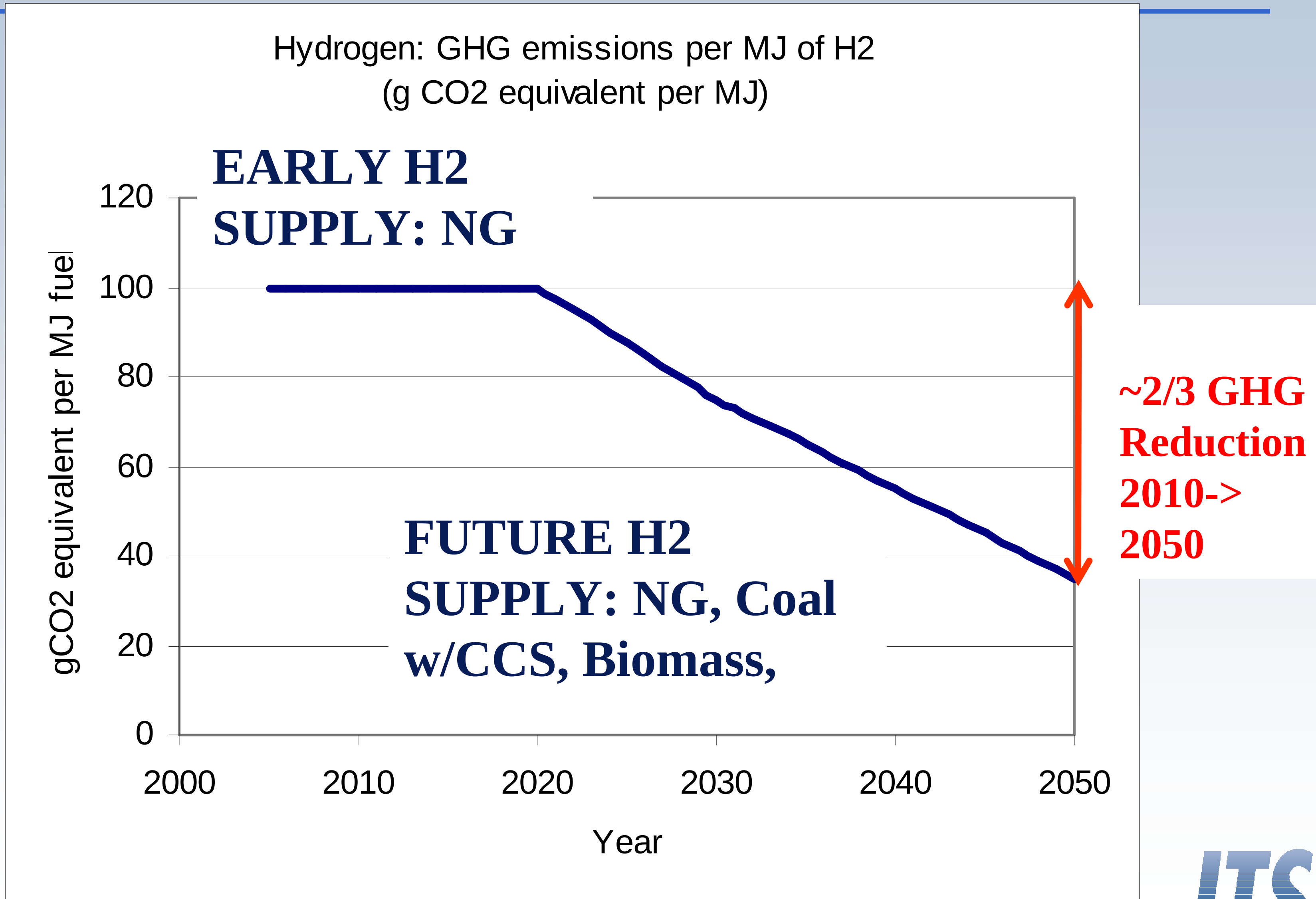
(gCO_2eq/kWh) (EPRI/NRDC)



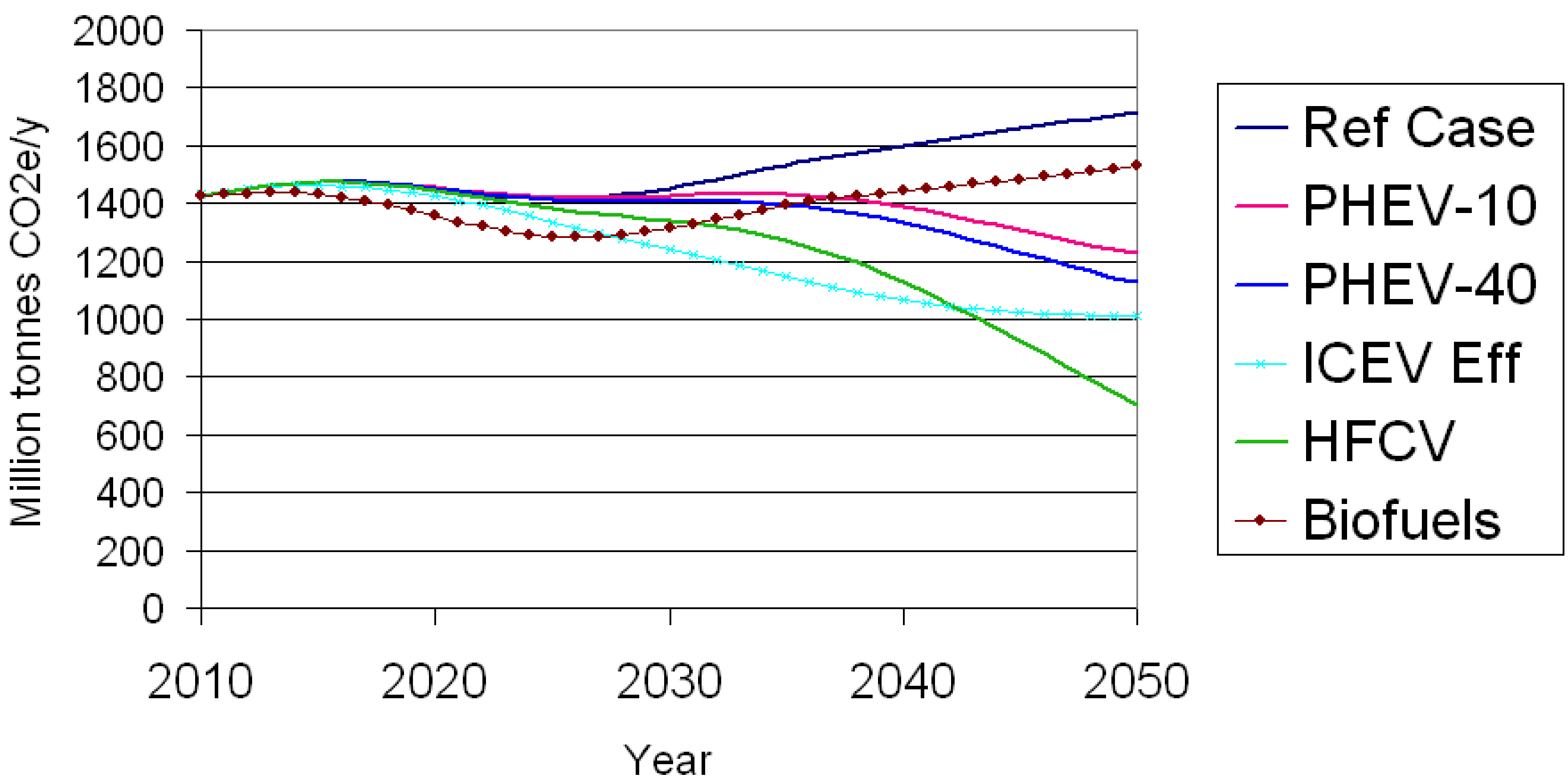
FUTURE GRID: Coal IGCC w/CCS, New Biomass, New Nuclear, Adv. Renewables

NRC H_2 Scenario: GHG Emissions Intensity

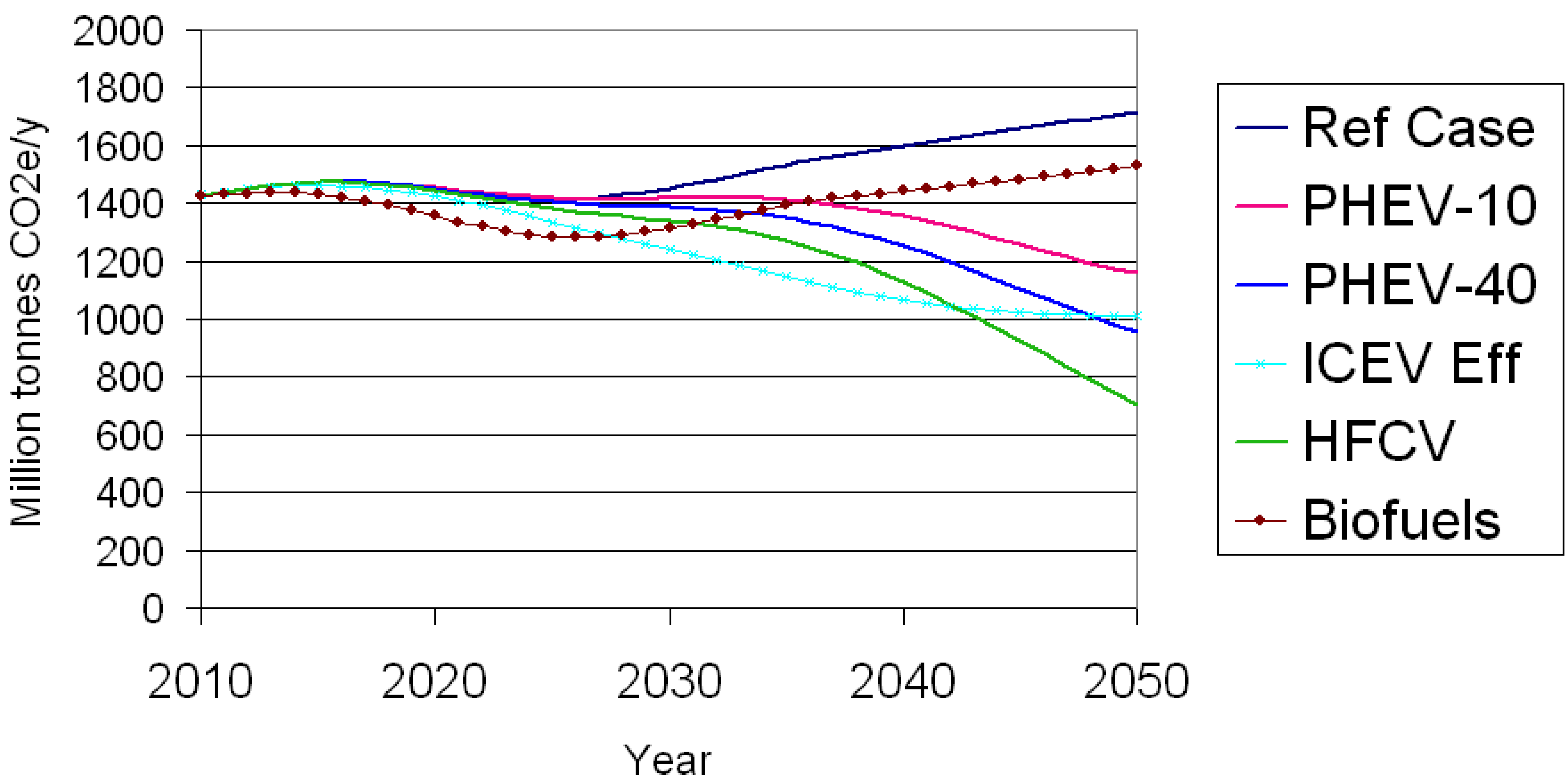
gCO_2/MJ H_2 (NRC 2008)



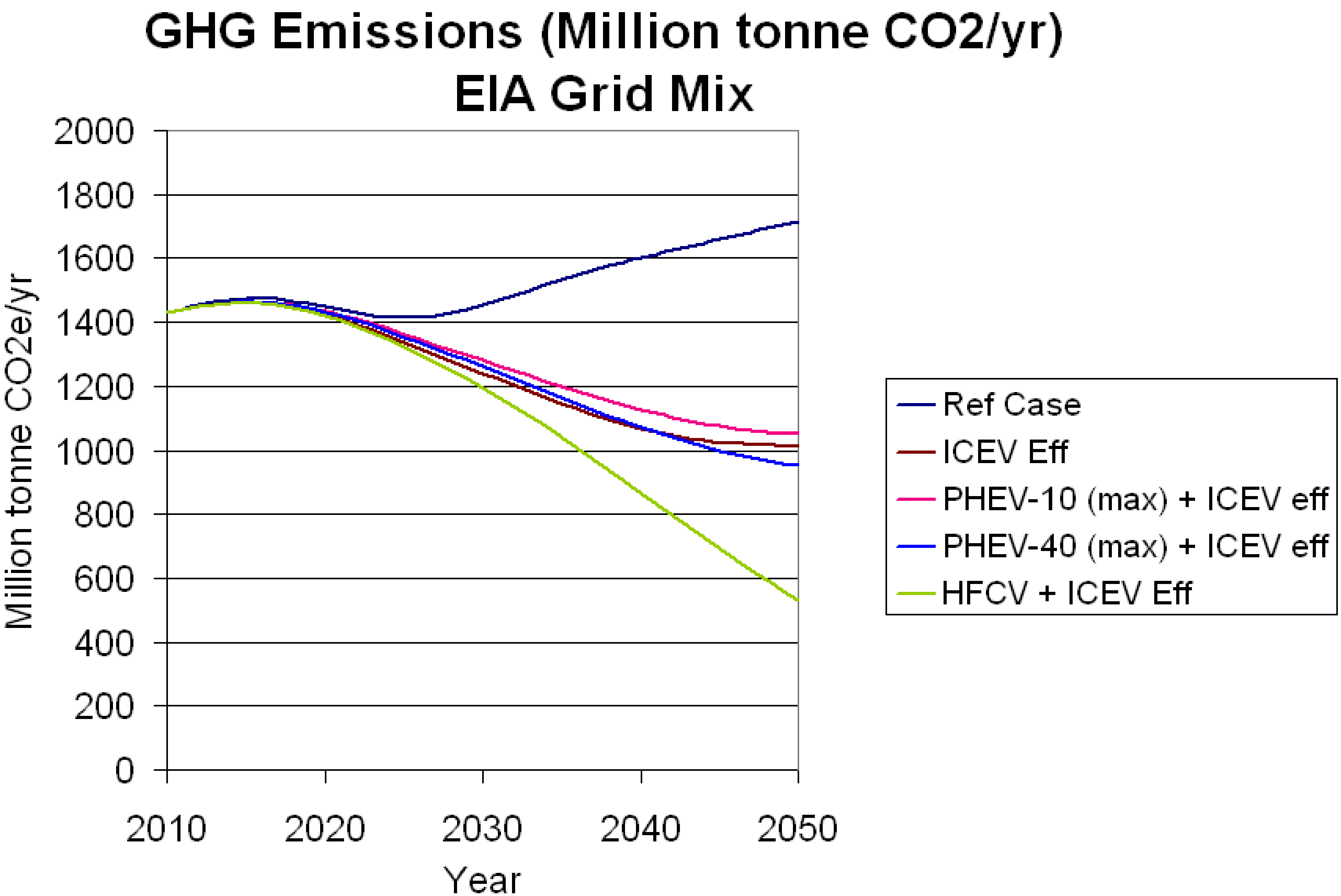
GHG Emissions for "Single Pathway" Scenarios (million tonnes CO2/y) EIA Grid Mix



GHG Emissions for "Single Pathway" Scenarios(million tonne CO2/y)EPRI/NRDC Grid



PORTFOLIO: ICEV EFF. + ADV. VEH (EIA GRID)



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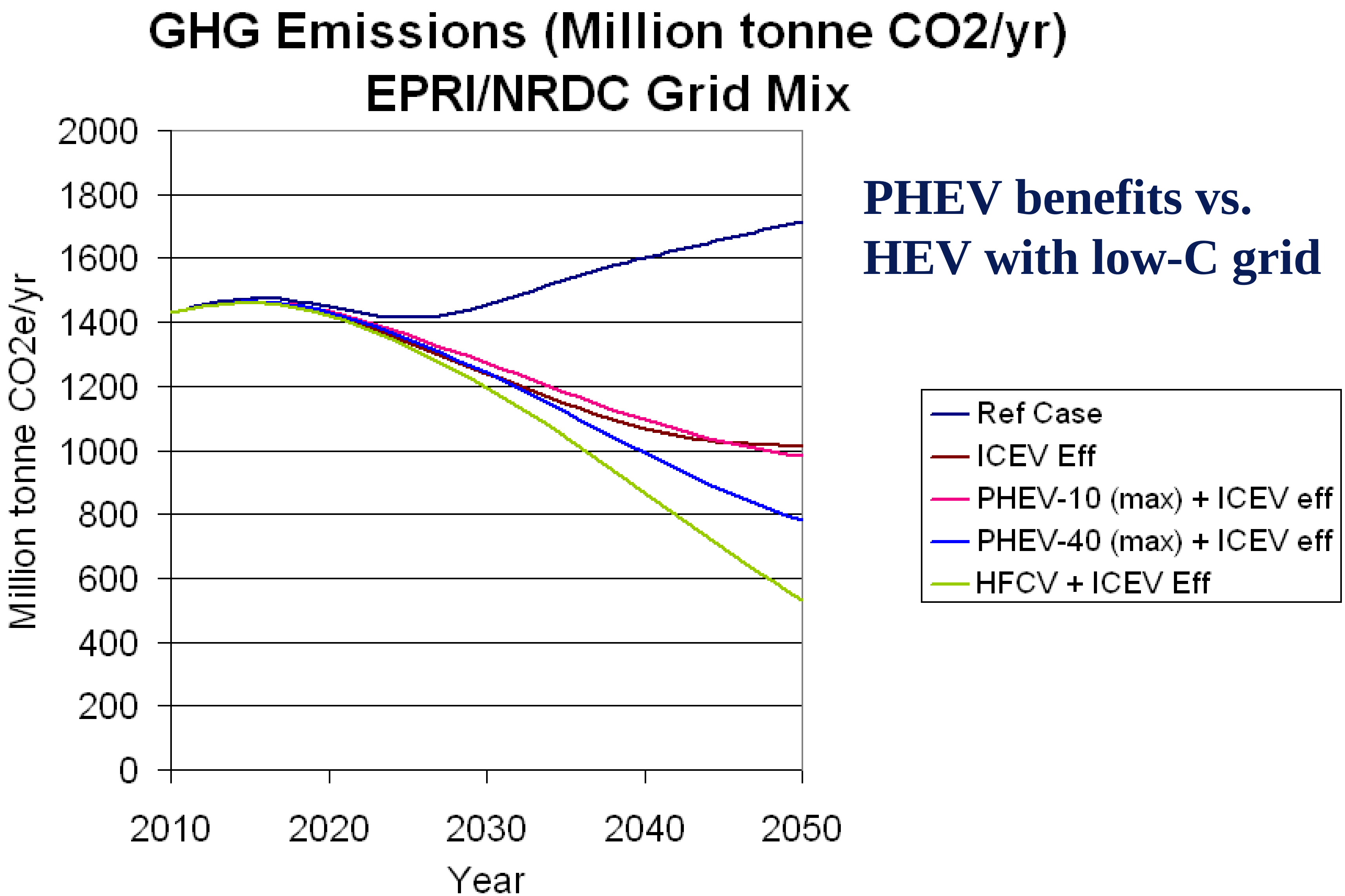
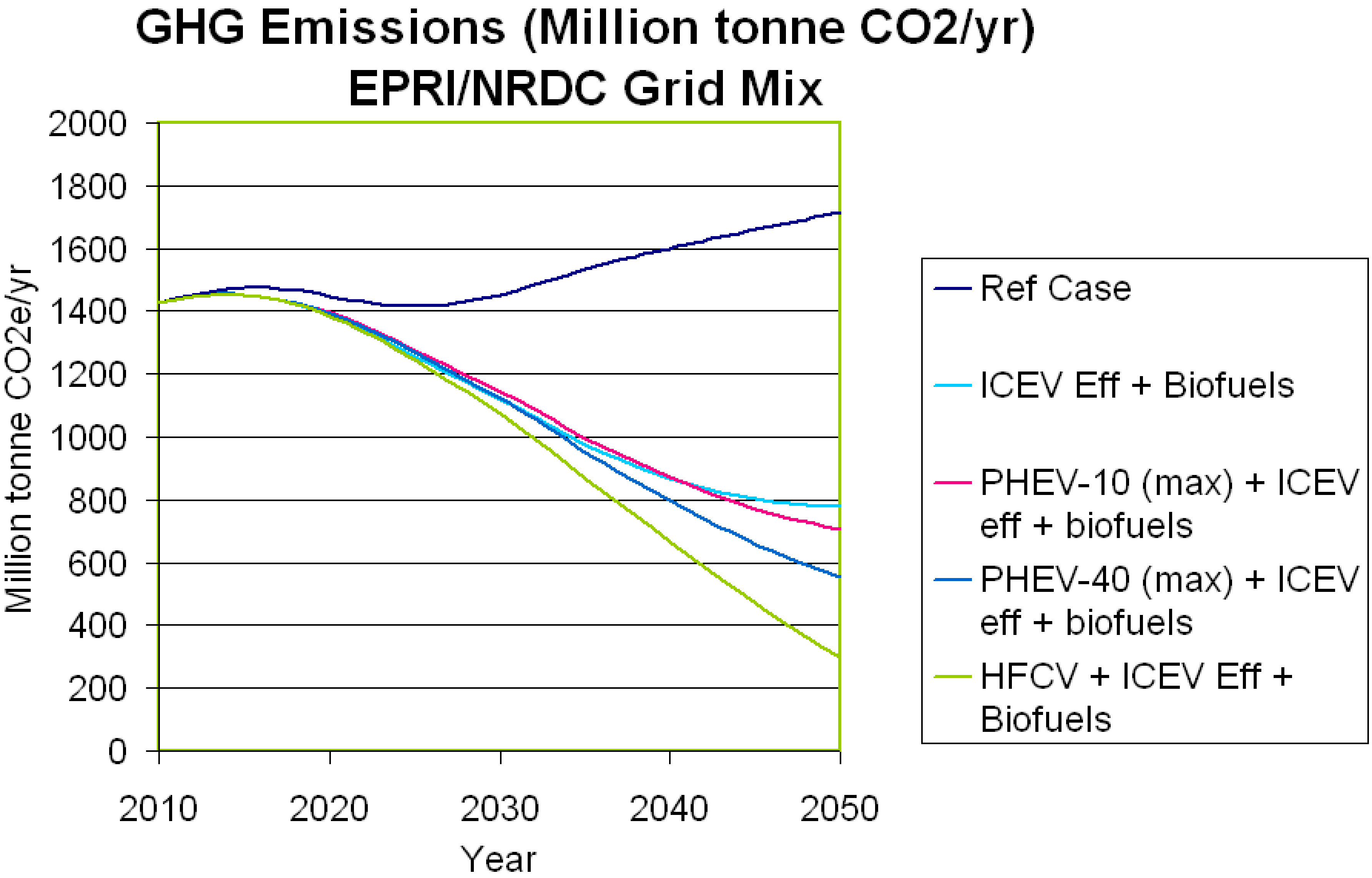
PORTFOLIO: ICEV EFF. + ADV.VEH (EPRI LOW-C GRID)



PHEV benefits vs. HEV with low-C grid

ICEV EFF. + ADV. VEH + BIOFUELS (LOW-C GRID)



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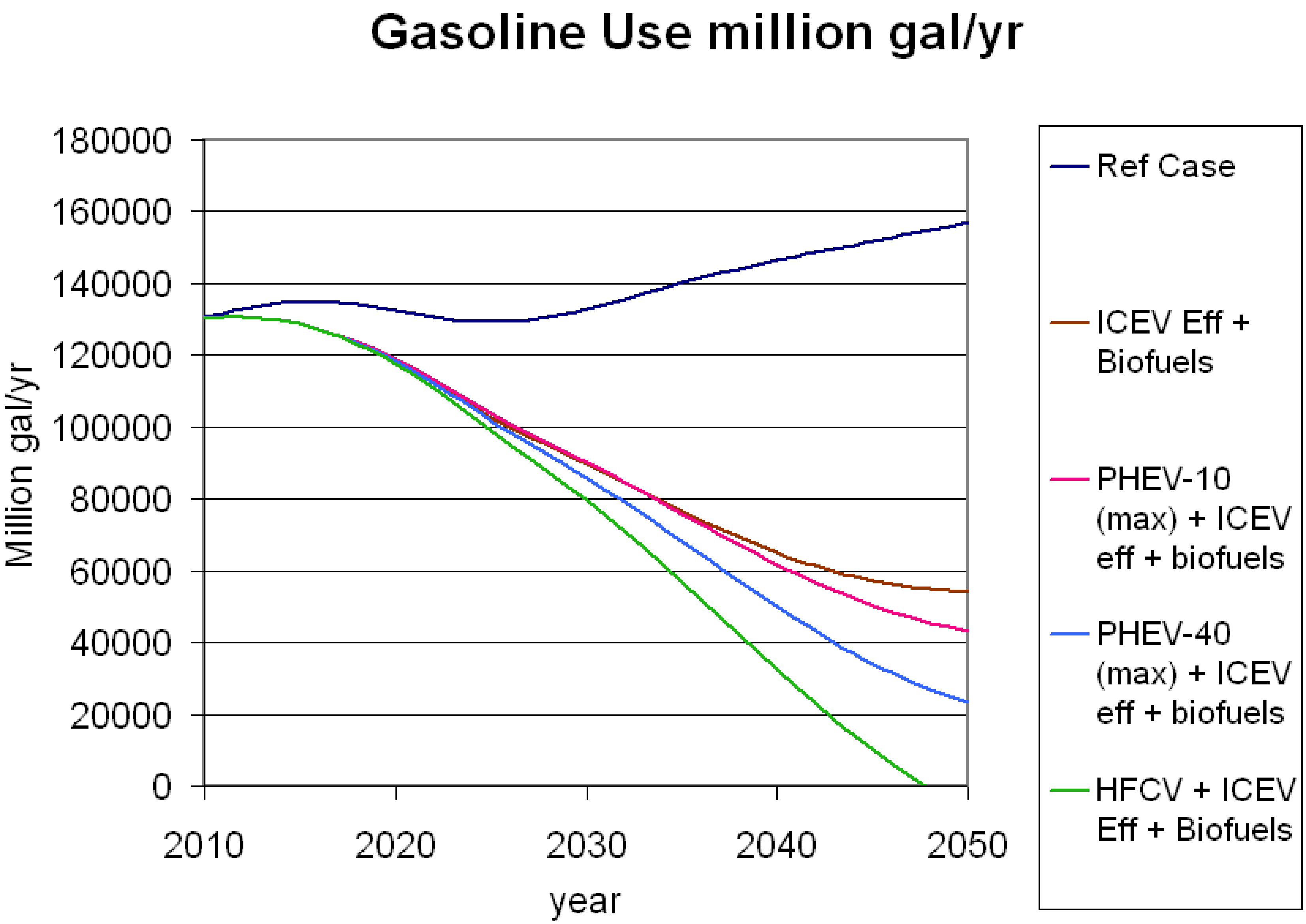
ICEV EFFICIENCY + ADV. VEH + BIOFUELS



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GHG Reduction Strategies

- Improved ICEV efficiency is key near-term measure
  - ~40% reduction in GHG emissions by 2050
- In longer term electric drive vehicles (EV,FCV), and decarbonized fuels (biofuels, elec, H2) important to reach 80% reduction goals.
  - Additional 20-40% GHG reduction possible by 2050
- No one single approach reaches 80% goal. Need portfolio approach
- Combinations of efficiency, decarbonized fuels and FCVs (or EVs) can reach 50-80% reductions
- Given long time for transition, need to start now

Societal Benefits PHEV and FCV

- PHEV GHG benefit depends on grid mix.
  - Ave. PHEV benefit small vs. HEV for marginal US grid
  - With Low-C grid, larger battery PHEVs => larger benefit
- H2 FCV GHG benefit depends on H2 supply mix
  - wtw GHG emissions for H2 FCVs ≤ HEVs (H2 from NG)
- GHG and oil reductions for PHEVs and FCVs small before 2025 because of time needed for vehicles to penetrate market.
- Long term GHG and oil use reductions are greater with FCVs than PHEVs for similar level of energy supply de-carbonization

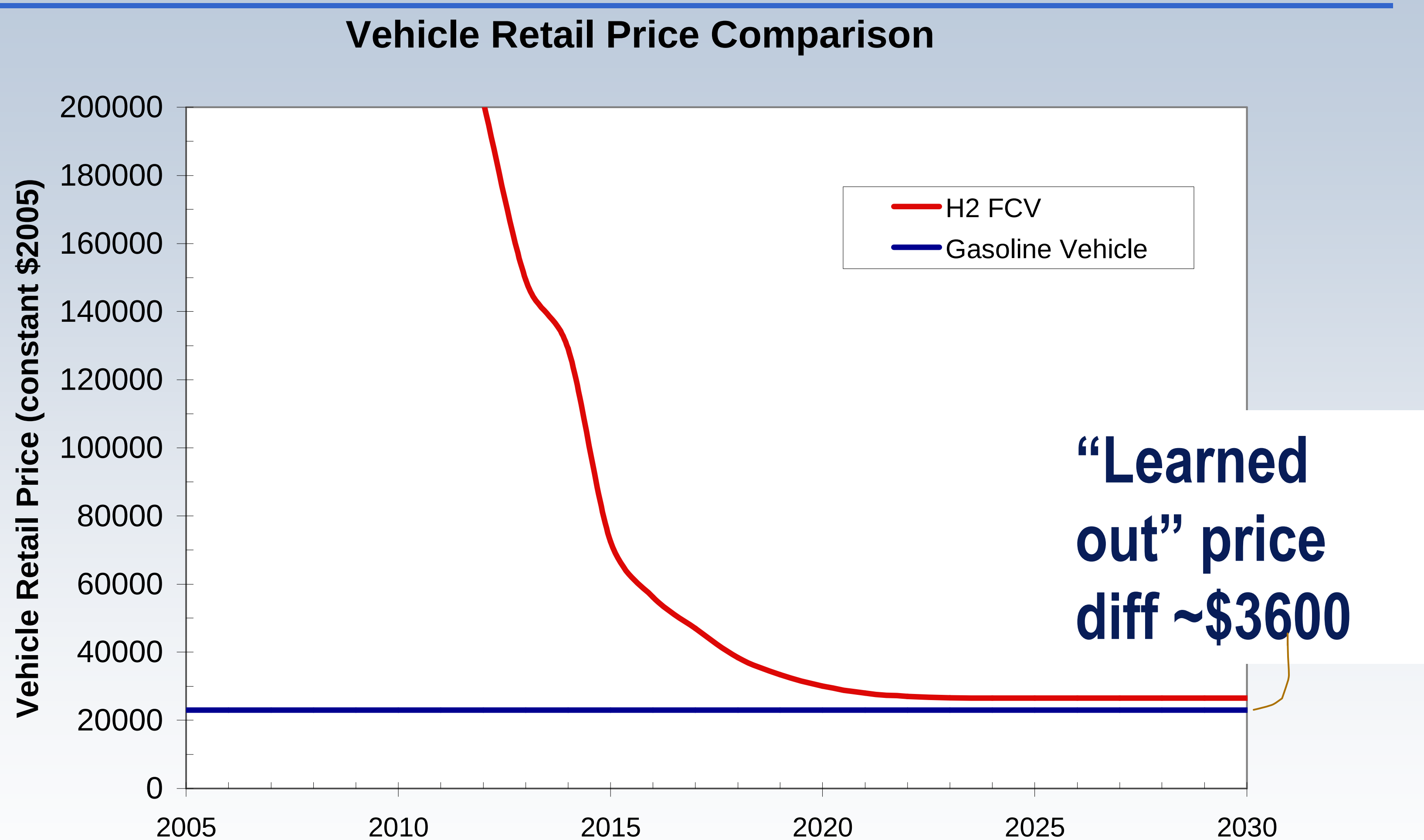
Part 2: Transition Cost Modeling

- **What are investment costs for H2 fuel cell or PHEV vehicles to reach cost competitiveness with reference gasoline vehicle?**

- **Conduct cash flow analysis to see when strategy of introducing H2 FCVs or PHEVs *breaks even* with BAU (staying with gasoline ref vehicle).**

- **Consider *cost differences* (gasoline-alt.fuel) $/y**
  - **first costs for vehicles**
  - **fuel costs**

H_2 FCV VEHICLE PRICE VS. TIME (NRC 2008)



H2 FCV Vehicle Price curve based on model by Greene, Leiby and Bowman (2007). Price falls due to R&D improvements, cumulative experience and manufacturing scale-up.

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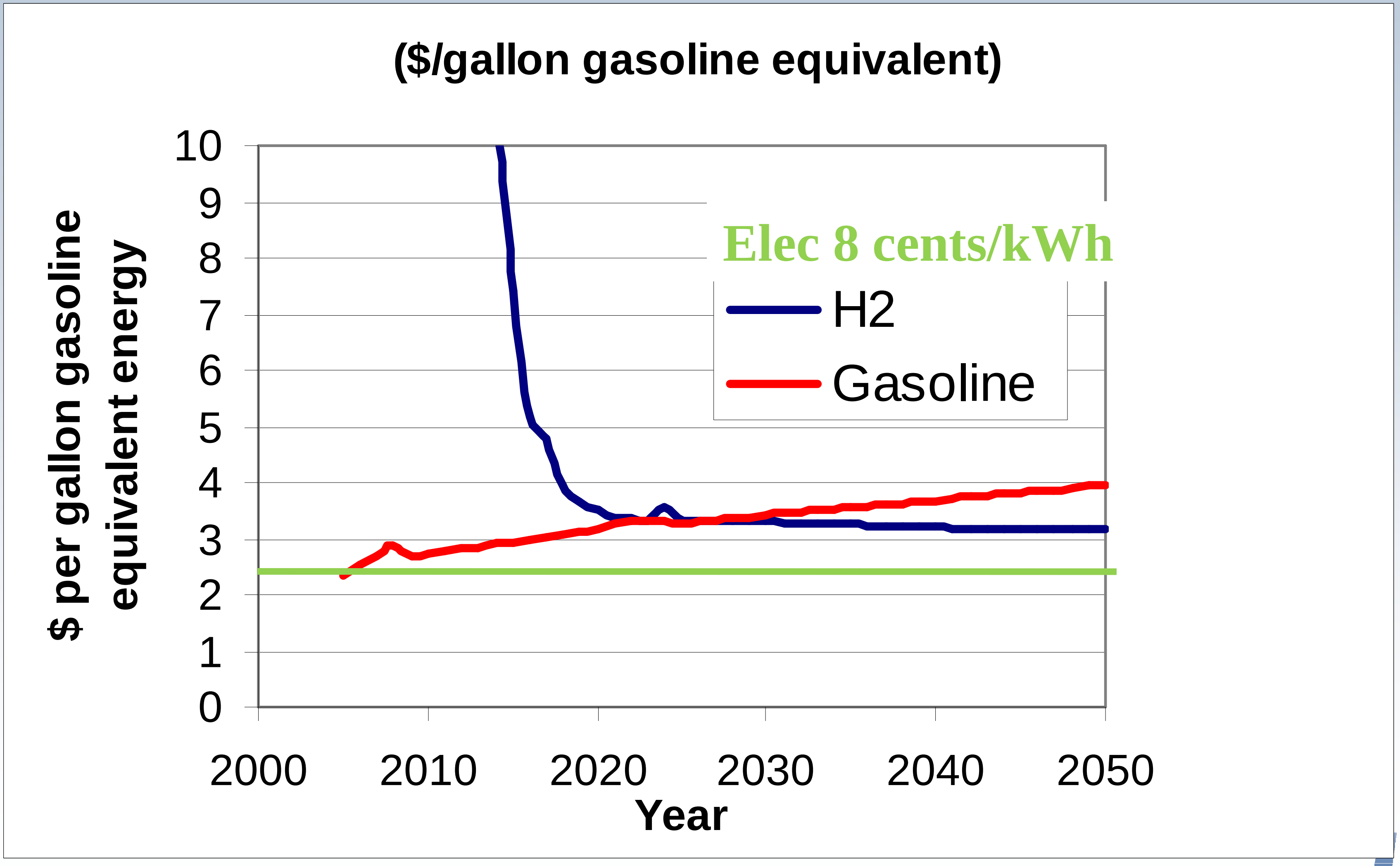
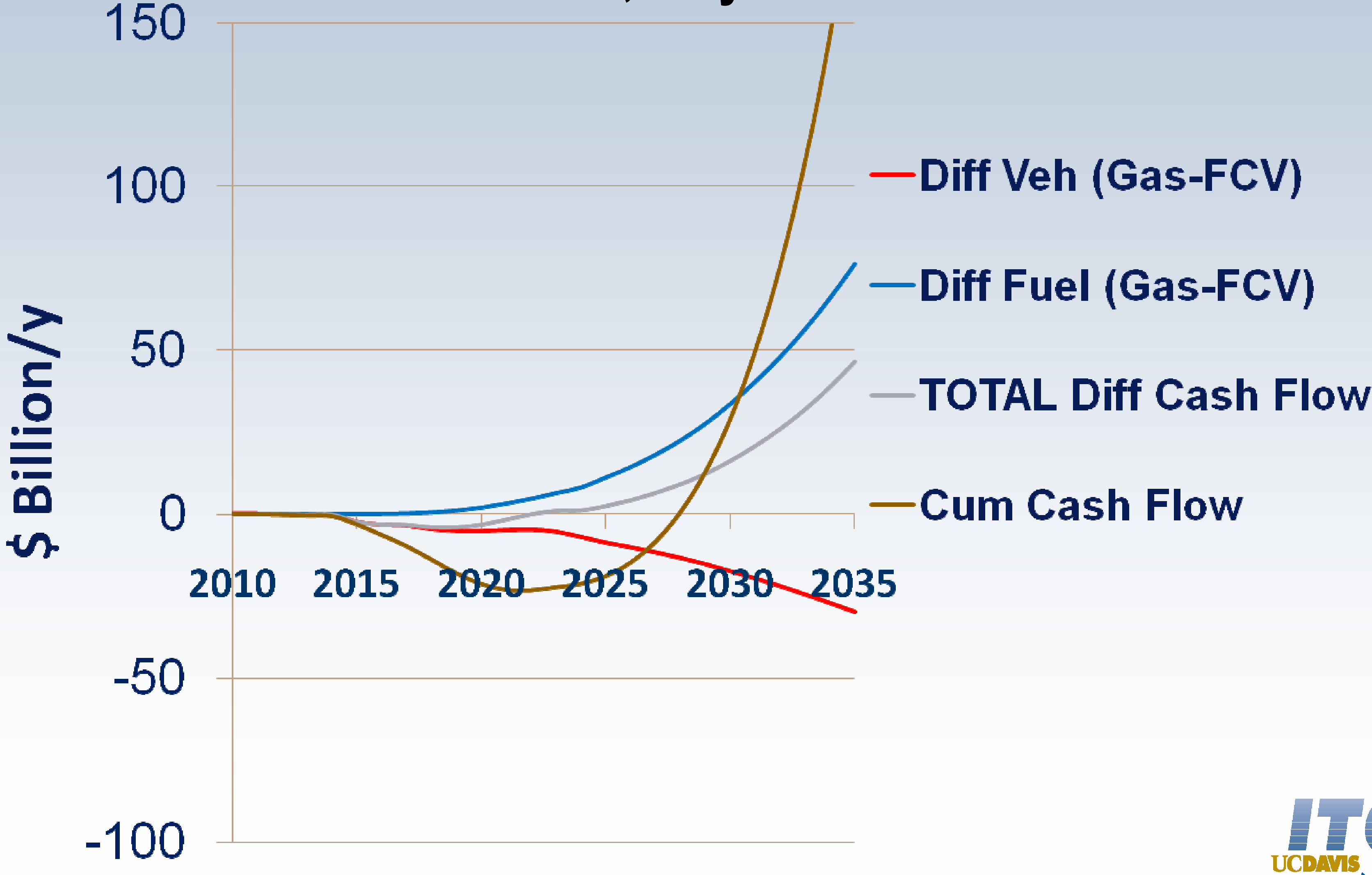
US Average Delivered H2 Cost (NRC 2008), Electricity and Gasoline price (EIA 2008)



H2 Transition Cash Flow Analysis

(H2 Success case NRC 2008)

Breakeven Year = 2023; Buydown Cost = $22 Billion



H2 Transition Timing and Costs (NRC 2008)

Breakeven Year (Annual Cash flow = 0)	2023
Cumulative cash flow difference (H2 FCV - Gasoline ref Car) to breakeven year	$22 Billion
Cumulative vehicle first cost difference (H2 FCVs-Gasoline Ref Car) to breakeven year	$40 Billion
# H2 FCVs cars at breakeven year (millions)	5.6 (1.9% of fleet)
H2 cost at breakeven year	$3.3/kg
H2 demand, # H2 stations at breakeven year	4200 t/d 3600 stations
Total cost to build infrastructure for demand at breakeven year	$8 Billion

H2 FCVs break even within about 10 years. Vehicle costs dominate

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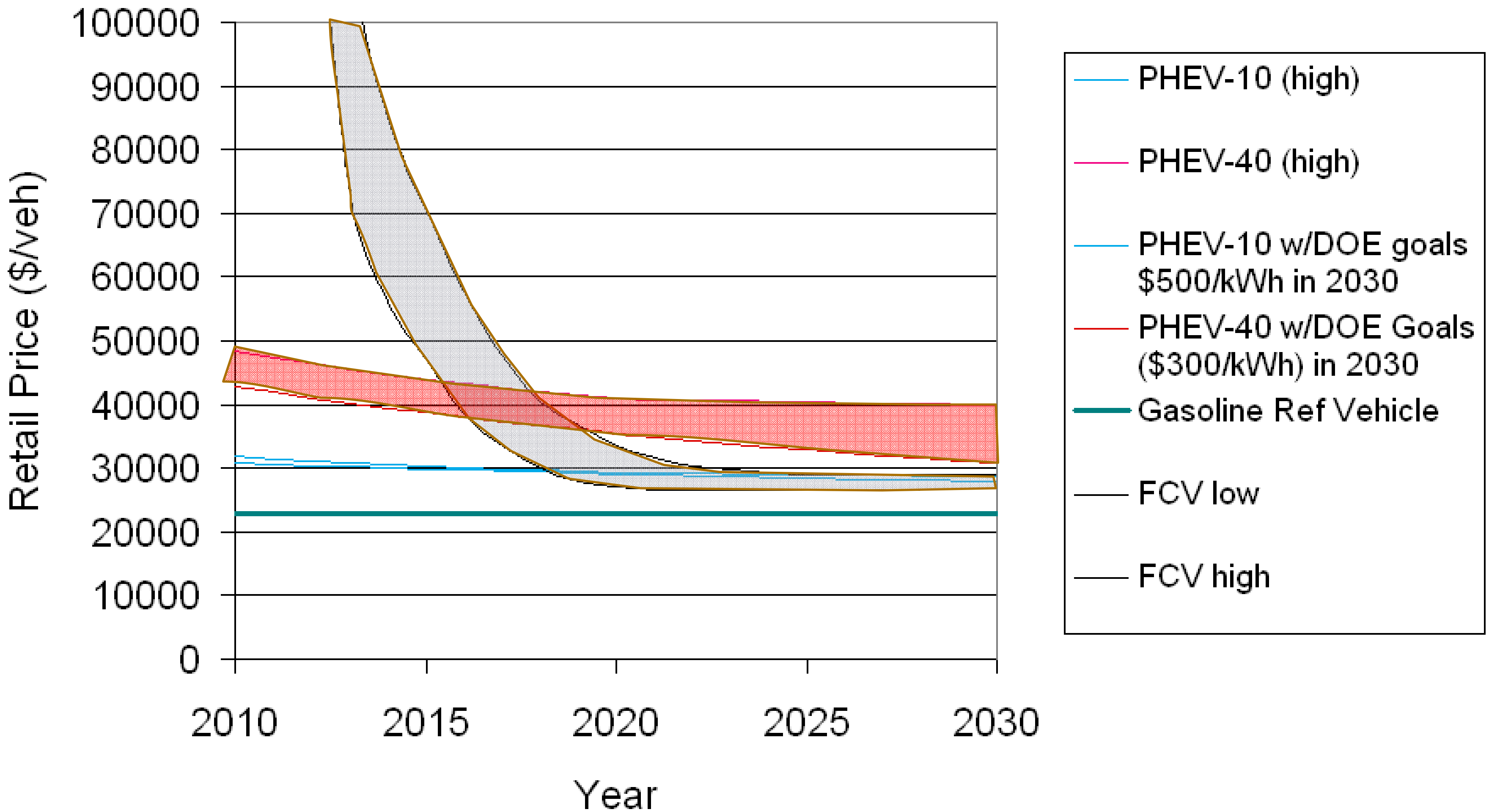
Vehicle Retail Price $/veh



PHEV Infrastructure Cost (DOE 2008)

IN-HOME CHARGING COSTS

- EV charging cord
- Residential Circuit upgrades
- Installation, Labor, Permits, administrative costs

Level 1: $800-900/car

Level 2: $1500-2100/car

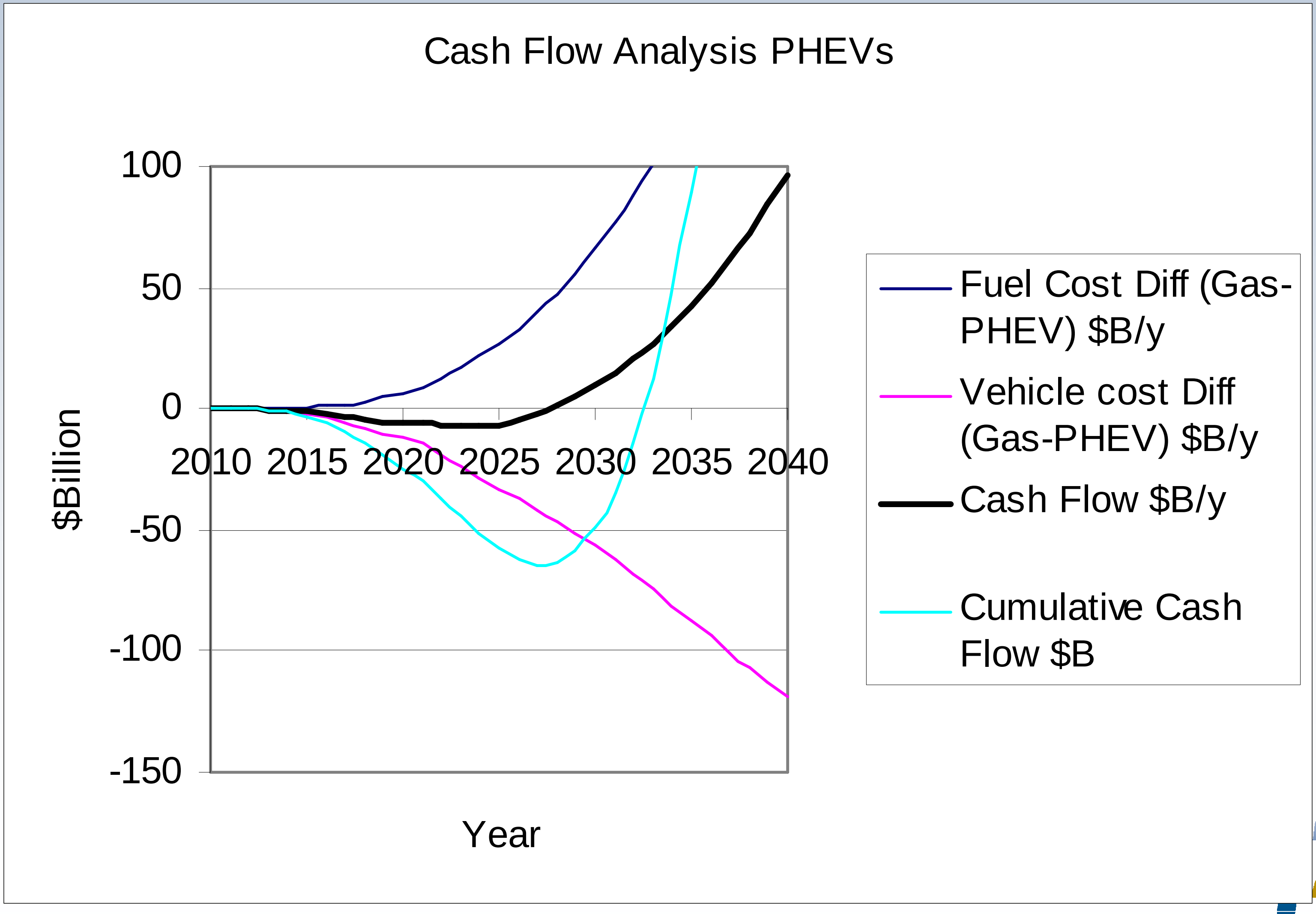
SYSTEM COSTS NOT INCLUDED IN THIS ESTIMATE

- Elec. Transmission and Distribution system upgrades
- Generation additions
- (Credits for system benefits with PHEVs?)

PHEV Transition Cash Flow Analysis

(mix of 30% PHEV-40s, 70% PHEV-10s)

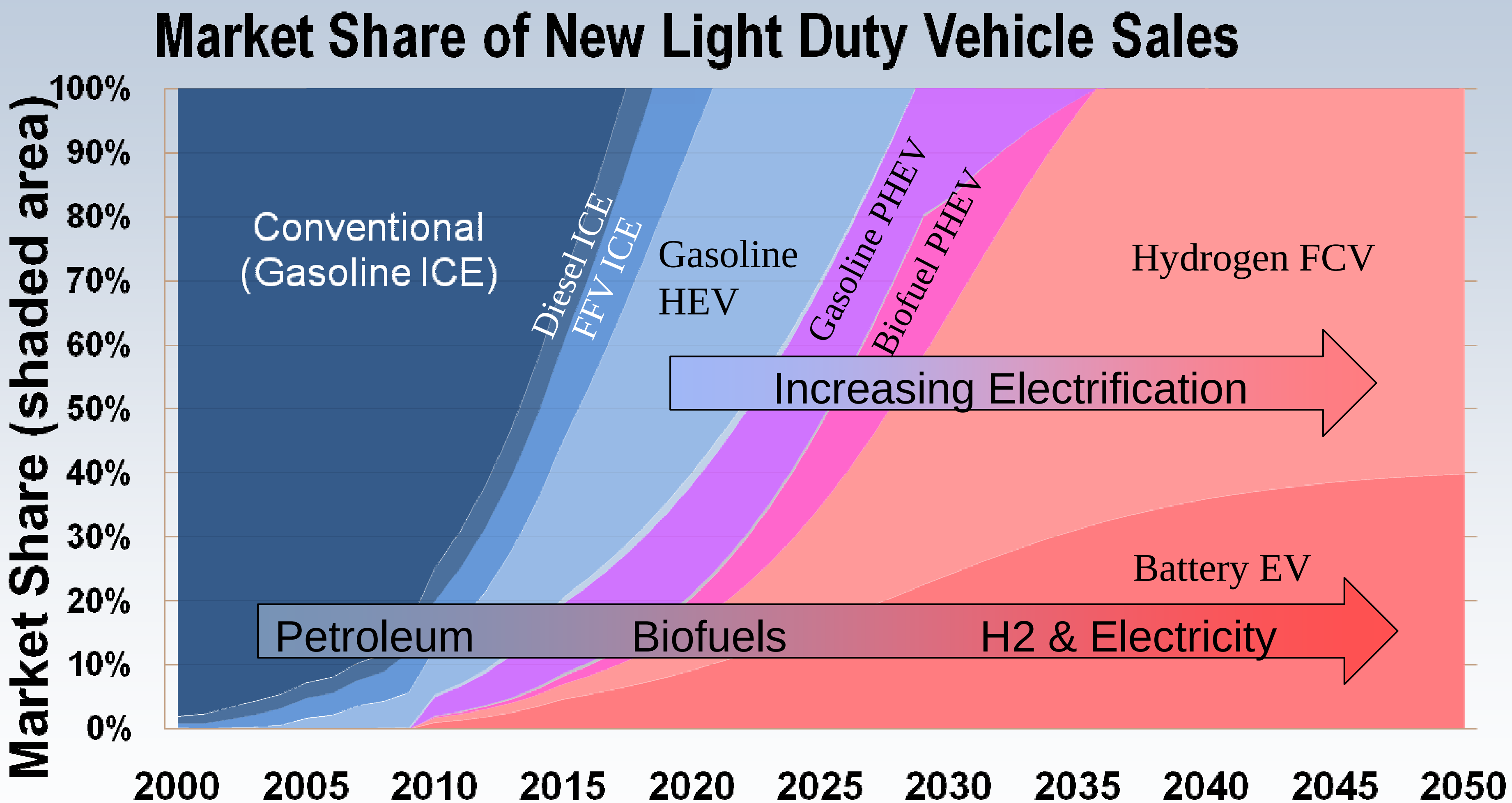
Breakeven Year = 2028; Buydown Cost = $60 Billion



Conclusions

- Transition costs, timing to “breakeven year” for FCVs, PHEV-10s ~10s of Billions of dollars total, spent over 10-15 period (larger battery incr. cost, time).
  - This is less than current corn ethanol subsidy of ~$10 B/yr.
- Majority of transition cost is for vehicle buydown ($\geq$80%).
  - Ave. price subsidy needed for FCVs and PHEVs over 10-15 transition period is similar ~$7000-9000/car.
  - Infrastructure cost per car $1500-2000/FCV; $550-1850/PHEV
- Critical vehicle technologies w.r.t. transition cost:
  - FCV: FC, H2 storage
  - PHEV: Adv. Battery

SCENARIO FOR CA LDV MARKETS TO REACH 80% REDUCTION IN GHG EMISSIONS BY 2050



W. Leighty and J. Ogden, "80in50 Path Analysis : Getting to 80% Reduction in Transport-related GHG emissions in California by 2050", UC Davis, 2009.